

Implementation of NASA Materials & Processes Requirements at the Goddard Space Flight Center

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July 23, 2009

Materials Engineering Branch History

- The Materials Engineering Branch has been responsible for supporting all Goddard Space Flight Center Projects with developing and implementing Materials & Processes (M&P) requirements for over 40 years
- The Branch was established around 1966 as the “Materials Research and Development Branch” and was part of Engineering
- Prior to 1966, the “Branch” was only a Section
- Renamed the “Materials Engineering Branch” in 1971



Circa 1974

Materials Engineering Branch History

- Moved to Flight Assurance (currently Safety & Mission Assurance) in 1976 and renamed the “Materials Controls and Applications Branch”
- Renamed the “Materials Branch” in 1986
- Moved back to Engineering in 1998 and renamed the “Materials Engineering Branch” again
- About a 50/50 split between Engineering and Assurance



Circa 1984

Early History of M&P Requirements at GSFC

- As early as 1966, Branch members were reviewing M&P lists
- The primary focus of these early reviews was outgassing, contamination, usage and previous materials-related lessons learned
- Following the move to Flight Assurance in 1976, consolidated M&P requirements were developed as part of the *Guidelines for Standard Payload Assurance Requirements (SPAR) for Orbital Projects*
- SPAR-3 (the final version of these requirements) was released in 1990, with the last revision released in 1992
- SPAR-3 called out requirements for material usage, flammability & toxic offgassing, vacuum outgassing, shelf life control of polymers, stress corrosion cracking susceptibility for metals, fastener integrity, lubrication, material processes, welding & brazing, and material procurement
- GSFC Management Instruction (GMI) 5340.1, *Implementation of the Goddard Space Flight Center (GSFC) Materials and Processes Program* was also released 1987
- GMI 5340.1 described the roles and responsibilities of the Project Manager, Flight Assurance Manager (now called CSOs), the Materials Engineering Branch, and the System Safety Branch in implementing a M&P program

ISO-9001 and Beyond

- In 1999, 300-PG-7120.2.1, *Mission Assurance Guidelines (MAG) Implementation* and 300-PG-7120.2.2, *Mission Assurance Guidelines (MAG) for Tailoring to the needs of GSFC Projects* replaced SPAR-3
- Eventually 541-PG-7120.2.1, *Materials Assurance Engineering Support Guidelines for Goddard Space Flight Center (GSFC) Projects* replaced GMI-5340.1 in 2003
- In 2006, the NASA M&P Working Group initiated the development of a standard set of M&P requirements for all NASA missions
- The initial goal of this activity was to develop a set of standardized requirements for the Constellation Program since multiple NASA Centers were supporting Constellation
- An interim version of NASA-STD-6016, *Standard Materials and Processes Requirements for Spacecraft* was released in September 2006
- The final consensus version was released in July 2008, with some modifications to accommodate requirements for non-human rated missions, which tend to be less stringent in some areas than the requirements for human-rated missions
- The consensus version of NASA-STD-6016 is currently being incorporated in the mission assurance requirements for GSFC missions

General M&P requirements in NASA-STD-6016

- **Materials will be selected to meet worst-case operational requirements**
- **Non-flight materials used to process flight hardware will not cause degradation of flight hardware**
- **A Materials and Processes Selection, Control, and Implementation Plan shall be developed and implemented by the organization responsible for the spacecraft flight hardware**
- **Design drawings and revisions shall contain a M&P approval block**
- **All M&P shall be defined by standards and specifications**
- **Each hardware provider shall establish a M&P Control Board**
 - **The responsible NASA M&P organization shall be a active and voting member of the board (with veto power)**
- **M&P usage will be documented in a Materials Identification and Usage List (MIUL)**
- **M&P that do not meet the requirements of NASA-STD-6016 shall be documented using a Materials Usage Agreement (MUA)**

Specific M&P Requirements from NASA-STD-6016

- Design allowables for structural materials shall come from Metallic Materials Properties Development and Standardization (MMPDS) and/or the MIL-HDBK-17
- Materials shall meet the requirements of NASA-STD-6001, *Flammability, Offgassing, and Compatibility Requirements and Test Procedures*
- MSFC-STD-3029, *Guidelines for the Selection of Metallic Materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments*, shall be used to select metallic materials to control stress corrosion cracking of metallic materials in sea and air environments
- Nonmetallic materials should be low outgassing per ASTM-E-595 (percent total mass loss <1.0, and percent collected volatile condensable <0.1)
- Materials exposed to the space environment shall be selected to perform in that environment (atomic oxygen, solar ultraviolet radiation, ionizing radiation, plasma, vacuum, thermal cycling, and contamination)
- Additionally, there are specific requirements for processes such as forging, castings, adhesive bonding, welding, brazing and soldering
- There are also specific requirements for nondestructive evaluation (NDE), residual stress mitigation, sandwich assemblies, corrosion prevention, hydrogen embrittlement, fasteners, contamination control and packaging

GSFC-Specific Modifications to NASA-STD-6016

- **For GSFC Non-human Rated Missions (which covers most of GSFC work), the M&P requirements in NASA-STD-6016 are tailored as follows:**
 - The developer is not required to have M&P drawing sign off
 - The developer may use GSFC forms or the developer's equivalent forms in lieu of the MAPTIS format for the MIUL
 - The developer does not need to follow the 3 tier MUA approach
 - The developer may use the GSFC outgassing database in addition to MAPTIS (<http://outgassing.nasa.gov>)
 - The developer shall use AFPCMAN91-710V3 Range Safety Users Requirements Manual section 10.1 in place of NASA-STD-6001
 - The developer shall qualify all lubricated mechanisms either by life testing in accordance with a life test plan or through heritage with an identical mechanism used in an identical application
 - The developer only needs to implement a Non-Destructive Evaluation Plan for fracture critical flight hardware
 - The developer shall use 541-PG-8072.1.2, *GSFC Fastener Integrity Requirements* in place of NASA-STD-6008
- **For Human-rated Missions, GSFC generally follows all the requirements called out in NASA-STD-6016**

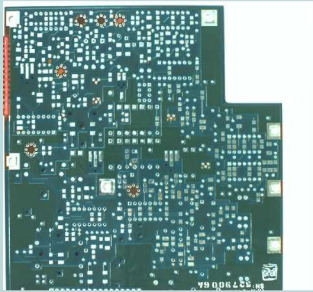
Additional M&P-related Requirements

- **In addition to the M&P requirements from NASA-STD-6016, GSFC implements M&P-related requirements from the following documents:**
 - **NPD 8730.2C, *NASA Parts Policy***
(Applies to mechanical parts such as fasteners, bearings, studs, pins, rings, shims, piping components, valves, springs, brackets, clamps, and spacers. Also applies to manufacturing materials affecting the performance and acceptability of parts such as plating, solder, and weld filler material.)
 - **NPR 8735.1B, *Procedures For Exchanging Parts, Materials, and Safety Problem Data Utilizing the Government-Industry Data Exchange Program (GIDEP) and NASA Advisories***

Additional M&P-related Requirements

- **AFSPCMAN 91-710V3, Air Force Space Command Manual**
(Use the least flammable and least toxic materials)
- **Institute for Printed Circuits Standards**
 - **IPC-2221, *Generic Standard on Printed Board Design***
 - **IPC-2222, *Sectional Design Standard for Rigid Organic Printed Boards***
 - **IPC-2223, *Sectional Design Standard for Flexible Printed Boards***
 - **IPC A-600, *Acceptability of Printed Boards (Class 3 requirements)***
 - **IPC-6011, *Generic Performance Specification for Printed Boards (Class 3 requirements)***
 - **IPC-6012, *Qualification and Performance Specification for Rigid Printed Boards (Class 3/A requirements)***
 - **IPC-6013, *Qualification and Performance Specification for Flexible Printed Boards (Class 3 requirements)***

Printed Wiring Board Coupon Inspection

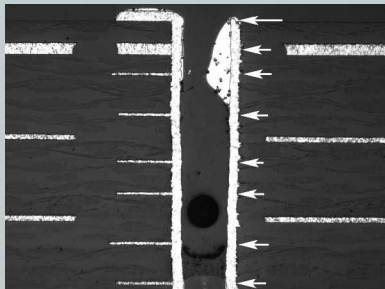


- When testing is done on bare boards, cost is minimal (~0.1% of board cost) and results are generated in two weeks or less. If board is rejected, it is usually replaced by manufacturer at no extra cost. Schedule slippage is also kept to a minimum.



- When defects are not discovered until the board is fully assembled, the cost is magnified many times over by loss of components, schedule slippage, labor costs, etc., stretching into 100's of thousands of dollars in loss.

- Coupon inspection at GSFC was first implemented in the 1980s when a board was found to be defective on a GOES instrument while the spacecraft was on the launch pad.



- Metallographic cross section analysis is conducted on coupons from all GFSC printed wiring boards because defects can pass through satellite electronic systems vibration and thermal vacuum testing and manifest themselves in orbit. (Figure shows defects in artwork or registration: missing internal and external annular rings.)

So how does the Materials Engineering Branch help GSFC Projects meet these requirements?

- **A Materials & Processes Engineer (MPE) is assigned to each GSFC Project**
 - **MPEs were formerly called Materials Assurance Engineers (MAEs)**
- **Early in a mission, the MPE supports the Chief Safety & Mission Assurance Officer (CSO) in developing Materials and Processes requirements**
- **The MPE reviews (and approves) the Materials and Processes Control Plan submitted by the developer for out-of-house missions**
- **The MPE develops and implements the Materials and Processes Control Plan for in-house missions**
- **The MPE reviews (and approves) all Materials and Processes used on a spacecraft or instrument**
 - **By participating on the Parts, Materials and Processes Control Boards (PMPCB) or MPCB (this is typical with out-of-house missions)**
 - **By reviewing Materials and Processes Lists (most common)**
 - **By reviewing Drawings (can be an effective approach, but may also be time consuming, typical for in-house Shuttle work)**
 - **By meeting with subsystem leads (sometimes necessary for in-house projects)**
 - **By auditing a subsystem suppliers (very occasionally)**

So how does the Materials Engineering Branch help GSFC Projects meet these requirements? (continued)

- **The MPE reviews materials-related GIDEP Alerts and Advisories**
- **Branch members attend design reviews (PDR, CDR, etc.)**
- **Branch members review (and approve) Materials Usage Agreements (MUAs) or Waivers concerning material issues**
- **Branch Metallurgists review (and approve) MUAs related to stress corrosion cracking**
- **Branch members audits subcontractor facilities as requested**
- **Branch members review (and approve) procurements as requested**
- **Branch members work with discipline engineers to address materials- and processes-related design issues**
 - **Supported a working group for TRMM to address atomic oxygen concerns**
 - **Co-chaired a working group to address life limiting issues with the JWST sunshield**
 - **Led the qualification of the SLIC composite structure**
 - **Conducted weekly meetings to address issues with the ISIM structure**
 - **Work with the Contamination Engineer to assure hardware cleanliness**
- **Branch members provide guidance on material selection and process development**

So how does the Materials Engineering Branch help GSFC Projects meet these requirements? (continued)

- **The MPE attends regular Project Systems Engineering meetings**
- **The MPE supports (engineering) champion meetings**
- **The MPE supports Division Technical Status Reviews (TSRs)**
- **The MPE stays abreast of ongoing investigations within the Branch being performed for his/her assigned Project(s)**
- **The MPE stays abreast of Branch capabilities and expertise**
- **The MPE apprises Project personnel of Branch capabilities**
- **The MPE advises Branch of future Project requirements**
- **The MPE ensures that Branch management is informed of activities that may have significant Project impact**
- **Senior MPEs are expected to become an “expert” in a space flight materials-related field such as composites, contamination, lubrication, polymers, etc.**
- **Branch members attend peer reviews**
- **Branch members participate as members on Anomaly or Failure Review Boards**
- **Branch members coordinate and document failure analyses of part and material failures**

MEB Laboratory Capabilities

Analysis

- Chemical Composition
 - Optical Emission
 - Energy Dispersive
 - X-ray Diffraction
 - Mass Spectrometry
 - FTIR
- Mechanical Testing
- Metallography
- Microscopy
 - Optical
 - Atomic Force
 - Confocal
 - Scanning Electron
- Surface Analysis
 - XPS
- Thermal Properties
 - Expansion
 - Conductivity
 - Specific Heat

Processes

- Bearing Cleaning
- Bonding/Staking
- Conformal Coating
 - Traditional
 - Parylene
- Heat Treatment
- Potting
- Precision Cleaning
- Vacuum Brazing

Qualification

- Bearing Life Testing
- Component Life Testing
 - Thermal
 - Vacuum
- Mechanism Testing
- Non-destructive Evaluation
 - Real Time x-ray
 - Ultrasonic
 - Eddy Current
 - Penetrant
- PWB Coupon Inspection
- Outgassing (ASTM-595)
- Thermal Cycling
- Vacuum Operation

Research

- CZT Mining
- MEMS Parylene
- Miniature Mass Spectrometer
- Air Coupled Ultrasonics
- Nano Technology
- Space Brazing
- Tribology

*The Branch has “experts” in the following areas:
Adhesive Bonding, Brazing & Welding, Ceramics & Glass, Composite Structures, Contamination Assessment, Cryogenic Testing, Failure Analysis, Life Testing, Metallurgy, NDE, Polymer Applications, PWB Manufacturing & Workmanship, Tribology, etc.*

Closing Remarks

- **Most M&P requirements flow from NASA-STD-6016, but these requirements can be tailored to the specific needs of a Project**
- **In general, GSFC follows NASA-STD-6016 for human-rated missions and a modified subset of the M&P requirements called out in NASA-STD-6016 for non-human rated missions**
- **Most M&P requirements come from over 40 years of experience with the use of materials and processes in aerospace applications**
 - as a result of ground testing at GSFC and other NASA Centers
 - and from lessons learned
- **The Materials Engineering Branch supports both Safety & Mission Assurance, and Engineering to assure mission success**



Circa 2002

Backup Slides

Polymeric Materials & Composites Usage List

POLYMERIC MATERIALS AND COMPOSITES USAGE LIST

SPACECRAFT _____ SYSTEM/EXPERIMENT _____ GSFC T/O _____

DEVELOPER/CONTRACTOR _____ ADDRESS _____

PREPARED BY _____ PHONE _____ DATE PREPARED _____

GSFC MATERIALS EVALUATOR _____ PHONE _____ DATE RECEIVED _____ DATE EVALUATED _____

Area, cm ²	Vol., cc	Wt., gm
1 0-1	A 0-1	a 0-1
2 2-100	B 2-50	b 2-50
3 101-1000	C 51-500	c 51-500
4 >1000	D >500	d >500

ITEM NO.	MATERIAL IDENTIFICATION ⁽²⁾	MIX FORMULA ⁽³⁾	CURE ⁽⁴⁾	AMOUNT CODE	EXPECTED ENVIRONMENT ⁽⁵⁾	REASON FOR SELECTION ⁽⁶⁾	OUTGASSING VALUES	
							TML	CVCM
	<p>NOTES</p> <p>1. List all polymeric materials and composites applications utilized in the system except lubricants, which should be listed on polymeric and composite materials usage list.</p> <p>2. Give the name of the material, identifying number and manufacturer. Example: Epoxy, Epon 828, E. V. Roberts and Associates</p> <p>3. Provide proportions and name of resin, hardener (catalyst), filler, etc. Example: 828/V140/Silflake 135 as 5/5/38 by weight</p> <p>4. Provide cure cycle details. Example: 8 hrs. at room temperature + 2 hrs. at 150C</p> <p>5. Provide the details of the environment that the material will experience as a finished S/C component, both in ground test and in space. List all materials with the same environment in a group. Example: T/V : -20C/+60C, 2 weeks, 10E-5 torr, ultraviolet radiation (UV) Storage: up to 1 year at room temperature Space: -10C/+20C, 2 years, 150 mile altitude, UV, electron, proton, atomic oxygen</p> <p>6. Provide any special reason why the materials were selected. If for a particular property, please give the property. Example: Cost, availability, room temperature curing or low thermal expansion.</p>							

Inorganic Materials & Composites Usage List

INORGANIC MATERIALS AND COMPOSITES USAGE LIST							
SPACECRAFT _____		SYSTEM/EXPERIMENT _____			GSFC T/O _____		
DEVELOPER/CONTRACTOR _____		ADDRESS _____					
PREPARED BY _____		PHONE _____			DATE PREPARED _____		
GSFC MATERIALS EVALUATOR _____		PHONE _____			DATE RECEIVED _____		DATE EVALUATED _____

ITEM NO.	MATERIAL IDENTIFICATION ⁽²⁾	CONDITION ⁽³⁾	APPLICATION ⁽⁴⁾ OR OTHER SPEC. NO.	EXPECTED ENVIRONMENT ⁽⁵⁾	S.C.C. TABLE NO.	MUA NO.	NDE METHOD
	<p>NOTES:</p> <ol style="list-style-type: none"> 1. List all inorganic materials (metals, ceramics, glasses, liquids and metal/ceramic composites) except bearing and lubrication materials, which should be listed on Form 18-59C. 2. Give materials name, identifying number manufacturer. Example: a. Aluminum 6061-T6 b. Electroless nickel plate, Enplate Ni 410, Enthone, Inc c. Fused silica, Corning 7940, Corning Glass Works 3. Give details of the finished condition of the material, heat-treat designation (hardness or strength), surface finish and coating, cold worked state, welding, brazing, etc. Example: a. Heat-treated to Rockwell C 60 hardness, gold electroplated, brazed. b. Surface coated with vapor deposited aluminum and magnesium fluoride c. Cold worked to full hare condition, TIG welded and electroless nickel-plated. 4. Give details of where on the spacecraft the material will be used (component) and its function. Example: Electronics box structure in attitude control system, not hermetically sealed. 5. Give the details of the environment that the material will experience as a finished S/C component, both in ground test and in space. Exclude vibration environment. List all materials with the same environment in a group. Example: T/V: -20C/+60C, 2 weeks, 10E-5 torr, Ultraviolet radiation (UV) Storage: up to 1 year at room temperature S pace: -10C/+20C, 2 years, 150 miles altitude, UV, electron, proton, Atomic Oxygen 						

Lubrication Usage List

LUBRICATION USAGE LIST							
SPACECRAFT _____	SYSTEM/EXPERIMENT _____			GSFC T/O _____			
DEVELOPED/CONTRACTOR _____	ADDRESS _____						
PREPARED BY _____	PHONE _____		DATE PREPARED _____				
GSFC MATERIALS EVALUATOR _____	PHONE _____		DATE RECEIVED _____	DATE EVALUATED _____			

ITEM NO.	COMPONENT TYPE, SIZE MATERIAL ⁽¹⁾	COMPONENT MANUFACTURER & MFR. IDENTIFICATION	PROPOSED LUBRICATION SYSTEM & AMT. OF LUBRICANT	TYPE & NO. OF WEAR CYCLES ⁽²⁾	SPEED, TEMP., ATM. OF OPERATION ⁽³⁾	TYPE OF LOADS & AMT.	OTHER DETAILS ⁽⁵⁾
	<p>NOTES</p> <p>(1) BB = ball bearing, SB = sleeve bearing, G = gear, SS = sliding surfaces, SEC = sliding electrical contacts. Give generic identification of materials used for the component, e.g., 440C steel, PTFE.</p> <p>(2) CUR = continuous unidirectional rotation, CO = continuous oscillation, IR = intermittent rotation, IO = intermittent oscillation, SO = small oscillation, (<30°), LO = large oscillation (>30°), CS = continuous sliding, IS = intermittent sliding. No. of wear cycles: A(1-10²), B(10²-10⁴), C(10⁴-10⁶), D(>10⁶)</p> <p>(3) Speed: RPM = revs./min., OPM = oscillations/min., VS = variable speed C P M = cm/min. (sliding applications) Temp. of operation, max. & min., °C Atmosphere: vacuum, air, gas, sealed or unsealed & pressure</p> <p>(4) Type of loads: A = axial, R = radial, T = tangential (gear load). Give amount of load.</p> <p>(5) If BB, give type and material of ball cage and number of shields and specified ball groove and ball finishes. If G, give surface treatment and hardness. If SB, give dia. of bore and width. If torque available is limited, give approx. value.</p>						

Materials Process Utilization List

MATERIALS PROCESS UTILIZATION LIST					
SPACECRAFT _____		SYSTEM/EXPERIMENT _____		GSFC T/O _____	
DEVELOPER/CONTRACTOR _____		ADDRESS _____			
PREPARED BY _____		PHONE _____		DATE PREPARED _____	
GSFC MATERIALS EVALUATOR _____		PHONE _____		DATE RECEIVED _____ DATE EVALUATED _____	

ITEM NO.	PROCESS TYPE ⁽¹⁾	CONTRACTOR SPEC. NO. ⁽²⁾	MIL., ASTM., FED. OR OTHER SPEC. NO.	DESCRIPTION OF MAT'L PROCESSED ⁽³⁾	SPACECRAFT/EXP. APPLICATION ⁽⁴⁾
<p>NOTES</p> <p>(1) Give generic name of process, e.g., anodizing (sulfuric acid).</p> <p>(2) If process is proprietary, please state so.</p> <p>(3) Identify the type and condition of the material subjected to the process. E.g., 6061-T6</p> <p>(4) Identify the component or structure of which the materials are being processed. E.g., Antenna dish</p>					

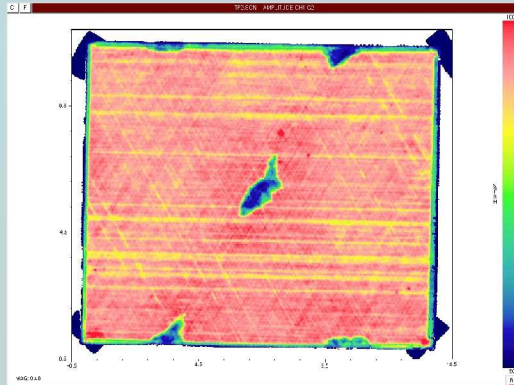
Materials Usage Agreement

MATERIAL USAGE AGREEMENT		USAGE AGREEMENT NO.:		PAGE OF	
PROJECT:	SUBSYSTEM:	ORIGINATOR:		ORGANIZATION:	
DETAIL DRAWING	NOMENCLATURE	USING ASSEMBLY	NOMENCLATURE		
MATERIAL & SPECIFICATION		MANUFACTURER & TRADE NAME			
USAGE	THICKNESS	WEIGHT	EXPOSED AREA	ENVIRONMENT	
				PRESSURE	TEMPERATURE MEDIA
APPLICATION:					
RATIONALE:					
ORIGINATOR:		PROGRAM MANAGER:		DATE:	

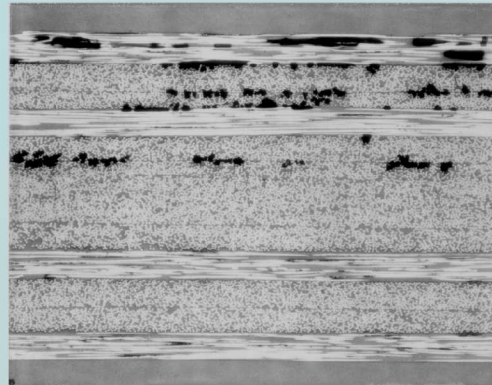
STRESS CORROSION EVALUATION FORM

1. Part Number _____
2. Part Name _____
3. Next Assembly Number _____
4. Manufacturer _____
5. Material _____
6. Heat Treatment _____
7. Size and Form _____
8. Sustained Tensile Stresses-Magnitude and Direction
 - a. Process Residual _____
 - b. Assembly _____
 - c. Design, Static _____
 9. Special Processing _____
 10. Weldments
 - a. Alloy Form, Temper of Parent Metal _____
 - b. Filler Alloy, if none, indicate _____
 - c. Welding Process _____
 - d. Weld Bead Removed - Yes (), No () _____
 - e. Post-Weld Thermal Treatment _____
 - f. Post-Weld Stress Relief _____
 11. Environment _____
 12. Protective Finish _____
 13. Function of Part _____
 14. Effect of Failure _____
 15. Evaluation of Stress Corrosion Susceptibility _____
 16. Remarks: _____

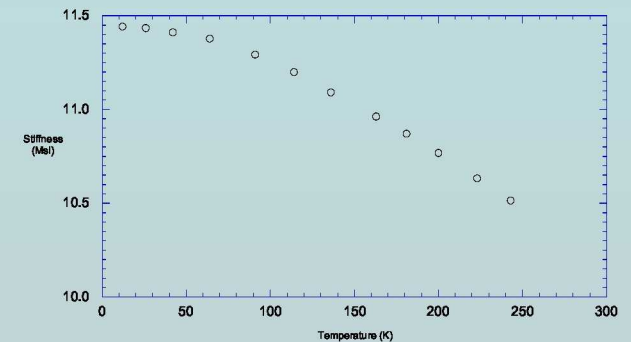
Characterization of Carbon Fiber Composites



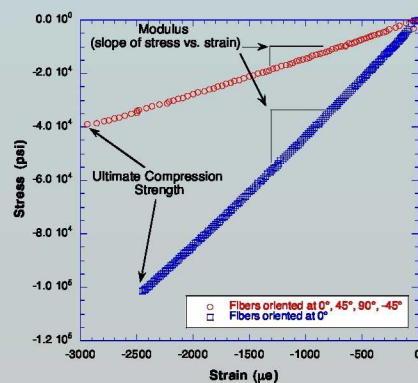
Ultrasonic Inspection



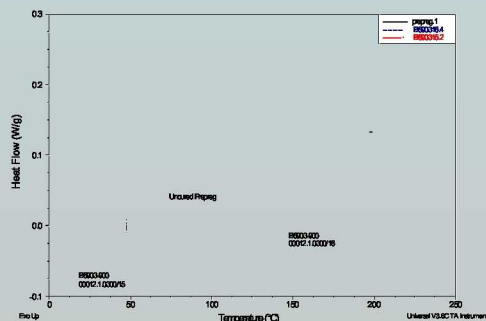
Metallographic Cross Section



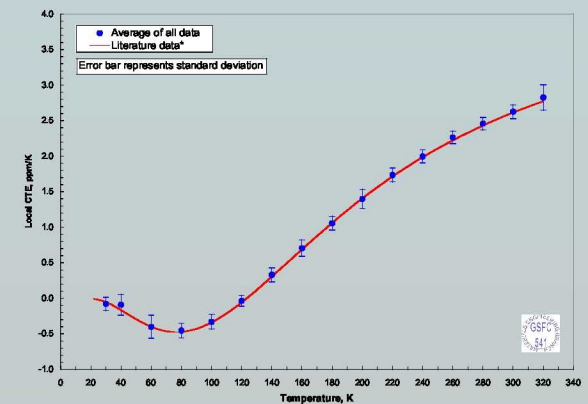
Elastic Modulus



Mechanical Strength Testing



Differential Scanning Calorimeter



* K.G. Lyon, G.L. Selinger, C.A. Swenson, G.K. White, "Linear Thermal Expansion Measurements on Silicon from 8 to 340K", J. Appl. Phys., Vol. 48, No. 3, 865-868 (1977)

Coefficient of Thermal Expansion